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The "RAPID" High Rate Area X-ray Detector System

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Abstract

Multiwire proportional counters (MWPCs) have been used for many years for small angle scattering and are particularly well suited to dynamic experiments. Their advantages include, almost zero noise, high dynamic range limited only by the electronic memory depth, large area and time frame resolutions of the order of tens of microseconds. They do, however, have some limitations, notably in global and local count rate performance.

The biological X-ray detector group at Daresbury has developed a two dimensional detector system which delivers a more than twenty-fold increase in throughput over the present systems. It comprises a "wire MicroGap" detector, which has much better local count rate performance than conventional MWPCs and a sophisticated multi-channel data acquisition system. The system has a global count rate capability of greater than 2×10^7 photons/sec with a maximum local count rate of greater than 10^6 photons/mm²/sec. A spatial resolution of $\sim 25\mu\text{m}$, over an active area of $12.8 \times 12.8 \text{ cm}^2$, has been achieved which compares well with existing readout systems. A $20 \times 20 \text{ cm}^2$ version is under development. Each electrode of the detector is instrumented with a preamplifier and ADC and the position of the event is determined independently in X and Y by centroiding the induced charge distribution. The X and Y co-ordinates are correlated using a unique time stamp. This paper describes the design and performance of the detector and readout system and presents some recent beamline results.

Introduction

The detectors which are currently used for small angle scattering are either count rate limited and therefore have to be attenuated (delay line MWPCs with a maximum rate of 10^6 photons/sec) or are noise

limited (image plates). A system capable of recording unattenuated diffraction patterns on the SRS with the same quality of data as is currently obtained with the delay line detectors opens up the possibility of higher time resolution experiments, less radiation damage or simply a considerable improvement in the overall throughput of work from the SRS.

RAPID, the **Refined ADC Per Input Detector** system is now undergoing preliminary beamline commissioning. It is a fast photon counting detector system with parameters similar to the existing delay line systems but with a factor of 20 improvement in count rate. The overall system specifications are given in Table 1.

RAPID System	
Detector type	Wire MicroGap
Active area of beamline detector	200mm x 200mm
Active area of prototype	128mm x 128mm
Maximum global counting rate	$> 10^6$ photons/sec/mm ²
Maximum local counting rate	$> 2 \times 10^7$ photons/sec
Upgradable to $\sim 10^8$ photons s ⁻¹	
Gas Filling	Xe Ar CO ₂
Drift depth	Adjustable, normally 15mm.
Efficiency @ 8 keV	80%
Number of pixels	Adjustable up to 8192×8192
Number of electronics channels	128×128 expandable to 256×256
Spatial Resolution	$\sim 250\mu\text{m}$ fwhm
Noise Level	$\sim 2.5 \times 10^{-4}$ cts/mm ² /s ¹
Number of frames	Variable depending on amount of memory. Up to 1024 images of 1024×1024 pixels or 4096 images of 512×512 pixels etc.
Time resolution	100ns
Spectral resolution	$\sim 20\%$ fwhm @ 8 keV

Table 1 Specifications of the RAPID data acquisition system

System description

RAPID consists of three parts.

1) A two dimensional wire MicroGap detector.

The new Daresbury-developed wire MicroGap detector technology yields a local count rate performance of approximately 10^6 photons/mm²/sec which is some two orders of magnitude greater than the conventional MWPC detectors. A wire MicroGap device is a central feature of the multiwire linear

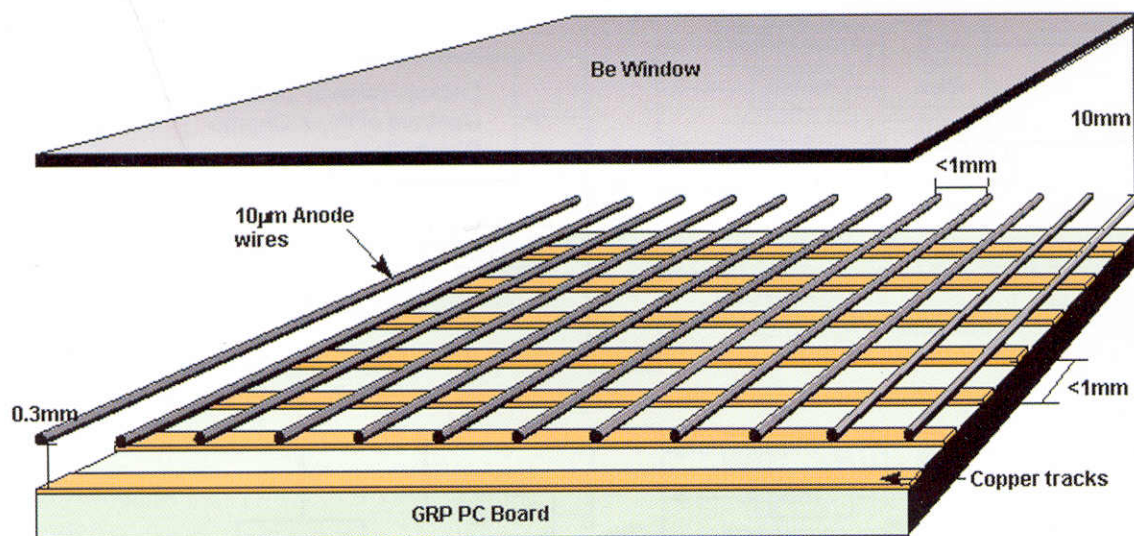


Figure 1 The two dimensional wire MicroGap detector

detector [1] which has been operational in various forms for five years [2]. The local count rate performance is such that it has proved capable of handling completely unattenuated diffraction patterns on station 16.1 which is the most intense X-ray source on the SRS.

The prototype RAPID detector is a two dimensional version of this technology with 128x128 electrodes on a 1mm pitch. The primary charge is spread over at least 2 anodes after it has drifted in from the point of interaction above the plane of the anode wires. With two or more anodes sharing the primary charge, interpolation can be performed on both anodes and cathodes; the signals for one co-ordinate are taken from the anode, whilst the others are taken from the cathode. The signal distribution on the anode channels is predictably quite different to that on the cathodes but this can be readily accommodated by the data acquisition system. In order to increase the active area, another detector having an active area of 200x200mm² but maintaining the 128x128 readout channels is under construction. The spatial resolution will be maintained by the use of a charge sharing network connecting the electrodes.

2) A very fast multi-channel data acquisition system

Due to the extreme complexity of the system, only a brief description follows. What follows is a short description of its operation. Each anode wire and cathode strip from the chamber is connected to one channel of the readout system. The signal path is split into two, one is with a 40ns shaping time connected to the 8 bit flash ADC, whilst the other has a faster 10ns shaping time and is connected to a

discriminator. The discriminator thresholds and amplifier gains and offsets are all individually adjustable from the software.

The ADCs normally free run at 80Mhz but when an event occurs, the discriminator outputs are used to adjust the clocks of the ADCs most closely surrounding the event. This then ensures that the pulse is sampled at its peak. The previous samples taken during free running mode are then subtracted from the peak samples to provide pulse height measurements with high immunity from pulse pile-up. Four neighbouring ADC channels in each dimension are simultaneously coincidentally triggered on each event. The pulse height data and a time stamp taken from the ~160Mhz master clock are communicated across a back-plane bus to the controller. Three of the four pulse height data are then selected to make the fine position and pulse height measurements which are performed. This is achieved using look up RAMs which contain data pre-calculated from the position and height algorithms. The coarse position of the event is derived from the pattern of discriminator hits.

The separate X and Y co-ordinates, which are derived from a combination of the fine and coarse positions, are time tagged to an accuracy of ~6.25ns and these data are then stored in dual ported RAMs for use by the X-Y correlator. This unit checks the temporal validity of the separate data, puts the X and Y data together with some error grading information on a bus and then transfers the data which then latched into the DL200 histogramming memory. Each electrode of the detector is instrumented with a preamplifier and ADC. The ADC samples from the

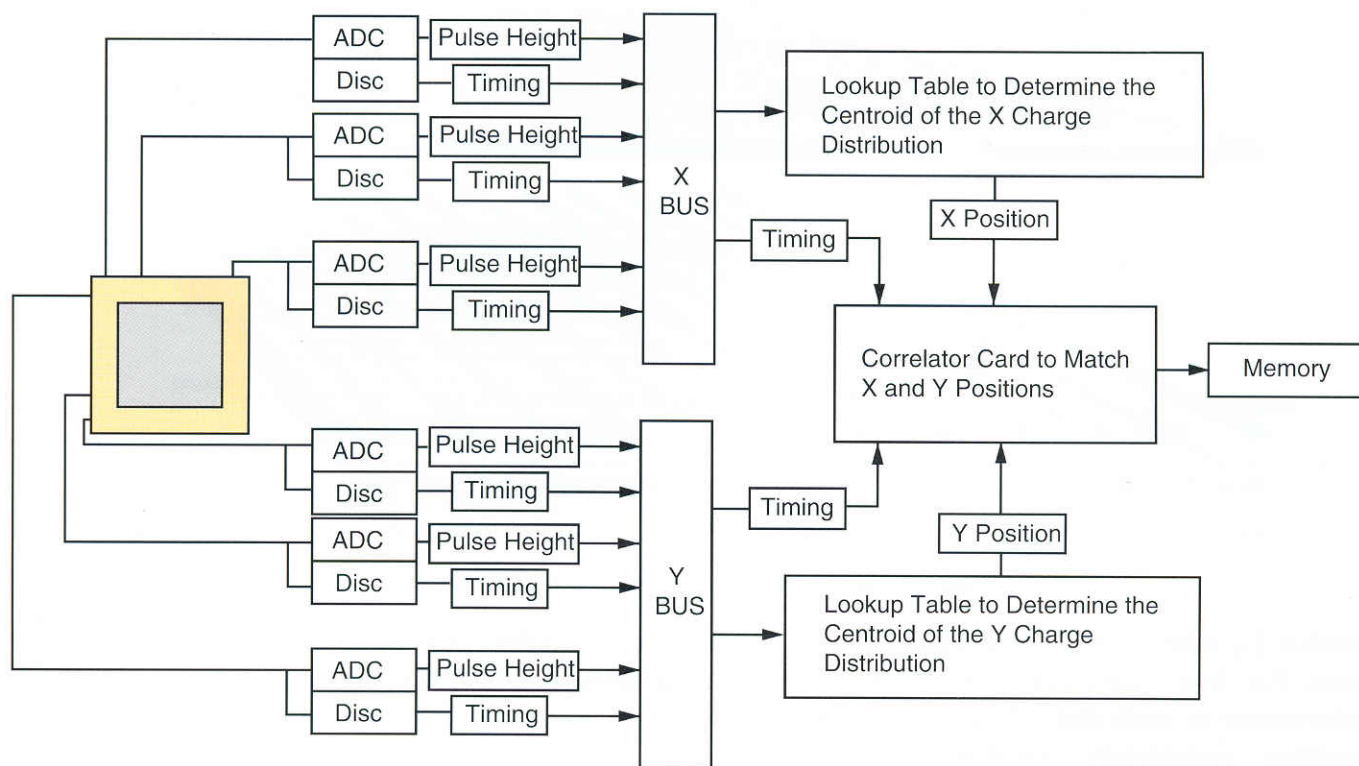


Figure 2 Block diagram showing the block structure of the fast 2 dimensional data acquisition system. The system has a master clock of 160 Mhz

four wires most closely surrounding an X-ray interaction are used to calculate the position of the event by interpolation.

The system has been designed to accommodate 256 channels in each dimension but cost constraints have limited the current system to 128x128 channels. The core of the system is contained in two 2m high racks, one for each dimension, and consists of nineteen printed circuit boards which have 18 layers and are 0.5m high. It is controlled by three VME computer systems and a fully populated system dissipates 8kW with each rack requiring water cooled heat exchangers. The multi-channel data acquisition system is capable of counting in excess of 2×10^7 photons/sec.

3) A fast histogramming memory system (DL200)

The Daresbury DL200 memory system which has been in routine use for a number of years with the delay line systems is one of the fastest large capacity histogramming memory systems in the world. It has a maximum capacity of 4Gbytes but its rate performance is limited to $\sim 5 \times 10^6$ counts/sec for extended periods, which is some four times slower than the expected performance of RAPID. The output of the RAPID system therefore produces four parallel data streams into four DL200 systems. The

upper bits of the memory address-word can be selected to represent time frames, if time resolved imaging is connected to it. The memory is dual ported, so the images can then be addressed by normal VME software to produce a real time display.

SRS Test results

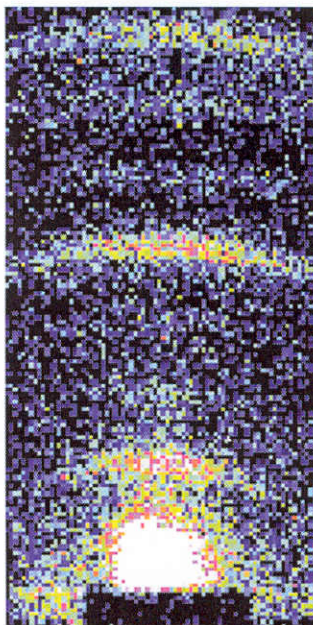
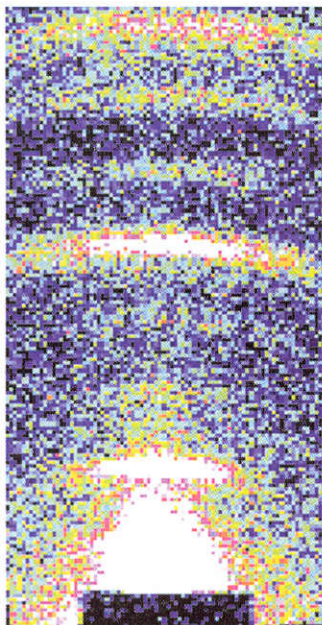
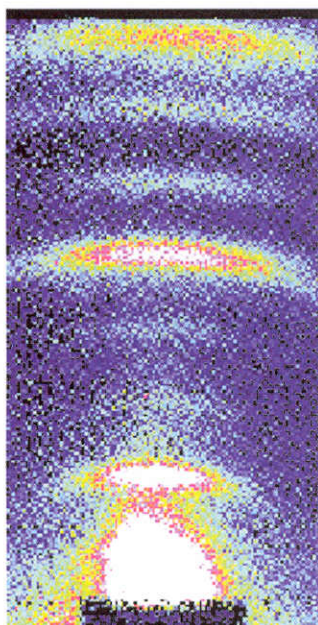
Tests of a subset of the RAPID system have very recently been carried out on the SRS station 16.1. Only six ADC boards were fully commissioned and so the system consisted of 64x32 channels covering an active area of 64x32mm.

Three detector systems, RAPID, a delay line area detector and an image plate were used to record various diffraction images at a camera length of 2.5m and an X-ray energy of 8.9keV. The maximum count rate that we were able to achieve using a polymer sample into a 60x30mm² area, which included the very intense region surrounding the beam stop, was 2.7×10^6 photons/sec. Fortunately, this rate corresponds to a rate of $\sim 2 \times 10^7$ photons/sec over the full system of 128x128 channels. As RAPID is a parallel system in which the rate performance scales with the number of channels, this represents a very realistic test of the rate capability of the system. The system proved capable of handling the maximum count rate that could be produced on 16.1 with no

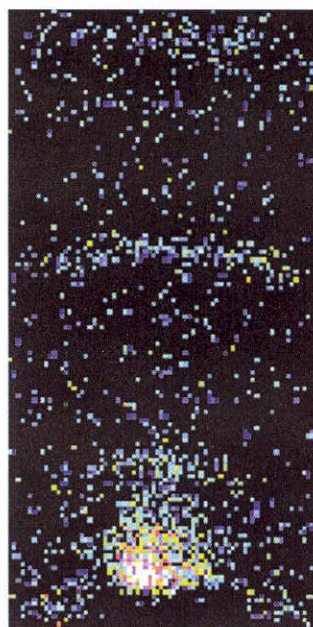
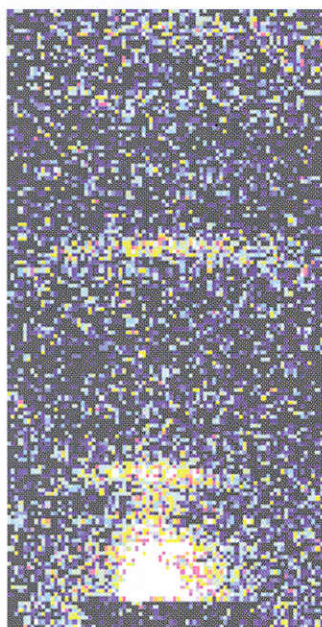
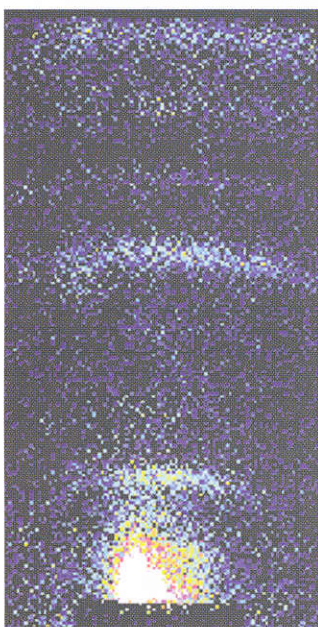
RAPID Detector
No attenuation

Image Plate
No attenuation

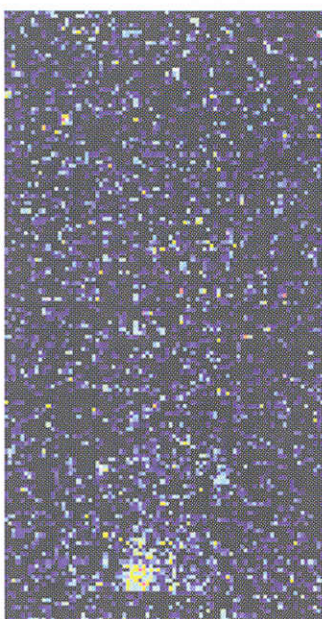
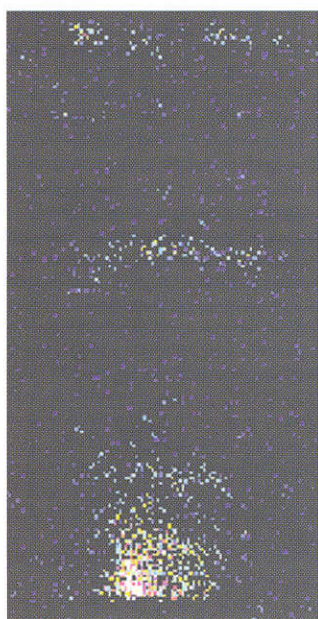
Delay Line Detector
9x attenuation



1 sec



100 ms



10 ms

Figure 3 Diffraction images of dry rat tail collagen taken on the three detectors at three exposure times.

attenuation at all. In contrast, the delay line detector required a 9x attenuator to be inserted in front of it, to reduce the count rate to a level which it could handle. The image plate of course required no attenuation.

Figure 3 shows diffraction images of dry rat tail collagen taken on the three different detector systems at 3 exposure times. The signal to noise in the RAPID images is clearly superior to that from the other 2 detectors with the 3rd, 6th and 9th order reflections being visible even from a 10ms single shot. The noise level of the image plate obliterates everything in the 10ms exposure whilst the 9x attenuator in front of the delay line detector means that there are insufficient photon statistics to make out any reflections.

During the tests, various problems with the RAPID system were identified. One of these problems can be seen in the intense part of the images where some structure is apparent which is not seen in the image plate data. This structure is caused by an under optimization of the interpolation algorithm which was used for these tests because there was insufficient information to perform the optimization. Now that we have a fully working system, we are confident that this can be corrected.

Conclusions

RAPID works and produces high quality 2-D images at a significantly higher rate than is possible with existing photon counting detectors. It is capable of handling unattenuated diffraction from the SRS from both polymers and biological samples and its noise performance is very much better than an image plate. The electronics commissioning is almost complete and the racks and cooling system are working well. The prototype MicroGap detector with active area of 128 x 128 mm is fully commissioned and working satisfactorily and a new 200 x 200mm active area detector with 128 x 128 electrodes is under construction.

Several difficulties have been identified and further work remains to be done. The calibration and interpolation algorithms must be optimized and system performance tests and characterisation performed. The 4 way striping of the memory system has to be implemented and the user software needs to be completed and debugged.

After completion of the system, integration with the

large area high pressure [3] technology will produce a high rate parallax reduced system for high angle diffraction.

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- [3] F. Ortuno-Prados, C.J.Hall, W.I. Heslby, A.O. Jones, R.Lewis, B. Parker, J. Sheldon *Nucl. Instrum. & Meths. A* (in press)

Neutron Diffraction Study of B-DNA Hydration

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A high angle neutron fibre diffraction study of the distribution of water around the B conformation of DNA has been carried out using the D19 diffractometer at the ILL, Grenoble. Datasets were recorded for DNA in both a D₂O and H₂O environment. Various data analysis techniques involving CCP13 software have been exploited to generate Fourier maps which show the water distribution around the DNA. An ordered water network has been observed in both the major and minor grooves. Refinement of these water positions is revealing a detailed picture of the hydration of this particular conformation.

Introduction

Understanding the structure and hydration of DNA is biologically extremely important. For example it has been shown that water molecules within the groove of the double helix stabilise protein-DNA interactions involved in the regulation of gene